

# OXYGEN AND IRON ABUNDANCES IN NEARBY GALAXIES USING ULTRALUMINOUS X-RAY SOURCES

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## ABSTRACT

We determined oxygen and iron abundances of the interstellar medium (ISM) using K-shell (O) and L-shell (Fe) X-ray photo-ionization edges towards Ultra luminous X-ray sources (ULXs). We determine the hydrogen column densities ( $n_H$ ) towards the ULXs from *XMM-Newton* archival spectra of 14 ULX sources. We compare our X-ray values with those obtained from radio HI observations for 8 of the sources. The X-ray model  $n_H$  values are in good agreement with the HI  $n_H$  values, implying that the hydrogen absorption towards the ULX is not local to the source, with the exception of M81 X-1. Oxygen abundances and iron abundances are roughly solar for the host galaxies.

Key words: ISM; ULXs; X-rays.

## 1. INTRODUCTION

Within our Milky Way, X-ray binaries have been used as a background through which to observe the 542 eV absorption edge produced by photoionization of the inner K-shell electrons of oxygen (Juett, Schulz, & Chakrabarty, 2004). For the first time, we attempt to extend this type of X-ray absorption study to external galaxies through the use of ultraluminous X-ray sources (ULXs).

## 2. SPECTRAL FITTING

We analyzed EPIC MOS and PN data from the *XMM-Newton* archive for 14 bright ULX sources. We required the X-ray spectra to have at least 5000 counts for this study. A majority of the sources were examined in Winter, Mushotzky, & Reynolds (submitted to ApJ), where the sources were fitted with simple absorbed black-body and power law models. In this study, we fit all of the sources with a base model of the *grad* model

(general relativistic multi-component disk) with a power law. We used the Wilms, Allen, & McCray (2000) abundances and absorption models (*tbabs* and *tbvarabs*). The *tbabs* absorption model was set to the Galactic value as obtained from the nH FTOOL in HEASARC, in order to account for Galactic absorption. We allowed the hydrogen column density, oxygen abundance, and iron abundance to remain free parameters within the *tbvarabs* model. As in Baumgartner & Mushotzky (submitted to ApJ), we found that the oxygen absorption values from the three EPIC detectors yielded different values. Thus, we followed the procedure of Baumgartner & Mushotzky (submitted to ApJ) in adding an *edge* model to account for the differences. We added an extra edge component to the MOS1 and MOS2 detectors at an energy of 0.53 keV with optical depths of 0.22 and 0.20 respectively. The sources and spectral fit parameters will be available in Winter, Mushotzky, & Reynolds (in preparation).

## 3. HYDROGEN COLUMN DENSITIES

We compared column densities obtained from the X-ray spectral fits with HI column densities for Holmberg II X-1, NGC 4559 X-7, NGC 4559 X-10, NGC 5204 X-1 (courtesy the WHISP catalog; Swaters et al. 2002) and NGC 247 X-1, M81 X-1, and Holmberg IX X-1 (Braun 1995). These are represented as circles in Figure 1. We also compare our values with columns obtained from the  $E_{B-V}$  values for M33 X-8 Long, Charles, & Dubus (2002) and M81 X-1 (Kong et al., 2000) using the relationship derived by Predehl & Schmitt (1995):  $n_H = 5.3 \times 10^{21} \text{ cm}^{-2} E_{B-V}$ . These are represented as triangles. The X-ray values correspond to the alternate measurements, with the exception of M81 X-1. For this source the X-ray column is greater, indicating the possibility of extra absorption surrounding the source.

This result is interesting considering that the X-ray measured column densities are along a direct line of sight to the ULXs while the HI measurements are an average over a larger beam area. The agreement between the two measurements implies that the ULX sources lie within

roughly normal areas of the galaxy (i.e. not in regions of higher column density such as a molecular cloud).

#### 4. O/H RATIOS

We compare the oxygen abundance values obtained from the X-ray spectral fits with those from studies of HII regions in Figure 2. The circles are a comparison with a study by Pilyugin, Vílchez, & Contini (2004) (P-method). Their method was based on spectrophotometric studies of HII regions in the host galaxies. We include with the circle symbols the O/H value obtained by Miller (1995) for Holmberg IX X-1 from an optical study of the surrounding HII region as well as the O/H value for NGC 1313 (8.4) obtained separately by Calzetti & Kinney (1994) and Walsh & Roy (1997). The triangle symbols represent a comparison with values obtained by Garnett (2002) using an alternate method (R23-calibration method). Our values are in better agreement with those of Garnett (2002).

We found that the ratio of Fe/H to O/H obtained through the X-ray spectral modeling (tbvarabs) was roughly the solar value. The iron abundance (from the iron L-shell edge located at 851 keV) was less well-constrained than the oxygen abundance. For the sources with greater number of counts ( $> 20000$  counts) and thus better constraints on abundances, the values for iron and oxygen do not deviate significantly from solar values. The values O/H and Fe/H correspond to:  $O/H = 12 + \log(O \times 0.00049)$ ;  $Fe/H = 12 + \log(Fe \times 2.69 \times 10^{-5})$ , where O and Fe are the abundances derived from the spectral fits using the Wilms solar values.

#### REFERENCES

- Calzetti, D. & Kinney, A.L. 1994, ApJ, 429, 582
- Garnett, D.R. 2002, ApJ, 581, 1019
- Juett, A.M., Schulz, N.S., & Chakrabarty, D. 2004, ApJ, 612, 308
- Kong, X. *et al.* 2000, AJ, 119, 2745
- Long, K.S., Charles, P.A., & Dubus, G. 2002, ApJ, 569, 204
- Miller, B.W. 1995, ApJ, 446, L75
- Pilyugin, L.S., Vílchez, J.M., & Contini, T. 2004, A&A, 425, 849
- Predehl, P. & Schmitt, J.H.M.M. 1995, A&A, 293, 889
- Swaters, R.A. *et al.* 2002, A&A, 390, 829
- Walsh, J.R. & Roy, J.-R. 1997, MNRAS, 288, 726
- Wilms, J., Allen, A., & McCray, R. 2000, ApJ, 542, 914

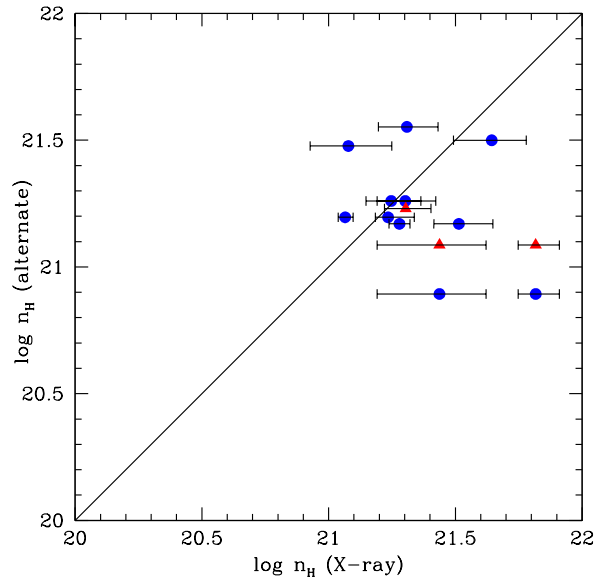


Figure 1. Comparison of the hydrogen column density obtained through the X-ray spectral fits with values from HI radio studies. The X-ray values are in good agreement with the radio measurements. The HI values are an average of the columns over a larger beam area while the X-ray values are a direct measurement along the line of sight to the ULX. This suggests that the sources have average column densities and therefore do not lie within special areas of the galaxy (such as a molecular cloud). The exception is M81 X-1 (the four outlying points) which may show evidence for extra absorption intrinsic to the source.

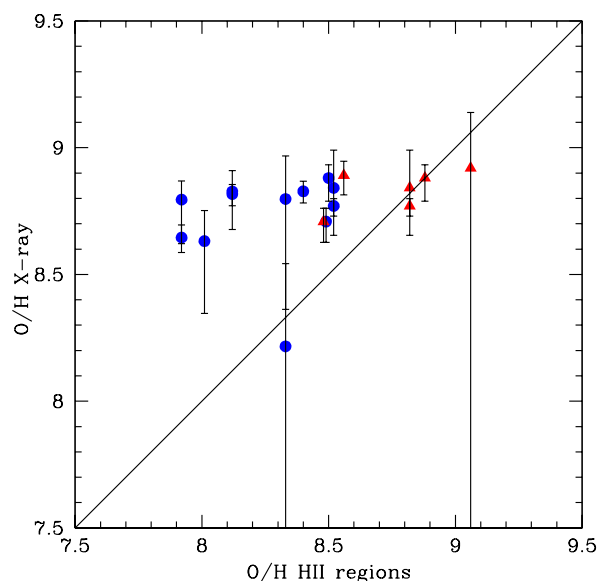


Figure 2. Comparison of the X-ray derived O/H ratios with those from optical/UV studies (see text). The values are in good agreement with those obtained by Garnett (2002). We note that the obtained oxygen abundances are roughly the solar Wilms values for all of the ULX sources.